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ATMOSPHERIC CORROSION OF TRANSMISSION LINE CONDUCTORS: ENVIRONMENTAL FIELD STUDIES

Report No. 90-199-K

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Environmental Science Section
Chemical Research Department

ABSTRACT

A short-term field study has been conducted to determine the air quality (suspended particle chemistry, SO_2 concentration in air, precipitation/fog chemistry) and meteorological conditions (temperature, relative humidity, wind speed and direction) of four sites, Etobicoke, Port Colborne, Guelph and Smiths Falls. In general, the pollutant levels are higher in Etobicoke and Port Colborne than Guelph, and lowest in Smiths Falls. The results of these studies generally support trends in the geographical distribution of key environmental parameters (e.g. SO_4^{2-}, Cl^-, NH_4^+ in precipitation; Ca in suspended particles; SO_2 in air; total amount of precipitation) in atmospheric corrosion of transmission line conductors. Environmental corrosion index ratings for the four sites were determined using an algorithm developed previously which considers threshold levels of key environmental parameters. Severe atmospheric corrosivities are indicated in Etobicoke and Port Colborne, median corrosivity in Guelph, and low corrosivity in Smiths Falls.

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EXECUTIVE SUMMARY

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Helen Leung and K.S. Yoshiki-Gravelsins
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Results of previous studies of the atmospheric corrosion of ACSR conductors have indicated the need for more complete environmental data, which are necessary to determine atmospheric corrosivities of locations across Ontario. These environmental assessments or ratings can be used in Ontario Hydro's transmission line refurbishment program to predict lifetimes of conductors and other transmission system components. A short-term field study has been conducted to determine the air quality (suspended particle chemistry, SO_2 concentration in air, precipitation/fog chemistry) and meteorological conditions (temperature, relative humidity, wind speed and direction) of four sites, Etobicoke, Port Colborne, Guelph and Smiths Falls. These sites were selected because: (i) they represent diverse environments; (ii) some long-term environmental data are available at these locations; and (iii) conductor samples from transmission lines in these areas have been analyzed. In general, pollutant levels were higher in Port Colborne and Etobicoke than in Guelph, and lowest in Smiths Falls. The results of this study generally support trends in the geographical distribution of key environmental parameters (e.g., SO_4^{2-}, Cl^-, NH_4^+ in precipitation; Ca in suspended particles; SO_2 in air; total amount of precipitation) in conductor corrosion. Deviations may be attributed to long-term variability in pollutant concentration, different study periods, and limitations of the contouring software program. Environmental

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corrosion index ratings for the four sites were determined using an algorithm developed previously which considers threshold levels of key environmental parameters. Severe atmospheric corrosivities are indicated in Etobicoke and Port Colborne, medium corrosivity in Guelph, and mildly-corrosive conditions in Smiths Falls. The data and analyses of this study will be useful in evaluating future dispersion modelling studies which will allow prediction of pollutant levels in the vicinity of sources and in areas remote from environmental monitoring stations.

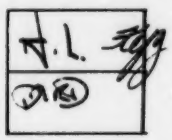

TABLE OF CONTENTS

		Page
1.0	**INTRODUCTION**	1
2.0	**FIELD STUDIES**	2
2.1	Air Quality Data	5
2.1.1.	Suspended Particles	5
2.1.2	SO_2 in Air	6
2.1.3	Precipitation	8
2.1.4	Fog Chemistry	10
2.2	Meteorological Data	11
2.2.1	Temperature	12
2.2.2	Relative Humidity	12
2.2.3	Wind Speed and Direction	13
3.0	**PRELIMINARY COMPARISON WITH ENVIRONMENTAL DATA BASE**	13
4.0	**SUMMARY**	14
REFERENCES		22
APPENDIX		23
DISTRIBUTION		last page

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ATMOSPHERIC CORROSION OF TRANSMISSION LINE CONDUCTORS: ENVIRONMENTAL FIELD STUDIES

1.0 INTRODUCTION

In support of the Transmission Line Refurbishment Program, the Environmental Science Section is currently carrying out research to identify pollutants that are responsible for atmospheric corrosion of transmission line conductors, and investigating means to predict the remaining life of these conductors. Recent studies [1,2] have identified key environmental parameters responsible for corrosion of these conductors (eg, SO_4^{2-}, Cl^-, NH_4^+ in precipitation; Ca in suspended particles; SO_2 in air; total amount of precipitation), and also the need for preparing a 'pollution climatology' of Southern Ontario. To date, an environmental database has been assembled from meteorological, air quality, precipitation chemistry and emissions data for Southern Ontario [3]. An environmental corrosion index [2] has also been developed to rate the atmospheric corrosivity of locations across Ontario. In order to improve our ability to predict the remaining life of conductors, a higher-resolution environmental database must be assembled, and the confidence with which environmental data from existing monitoring stations are assigned to transmission lines of interest must be established. The latter is of concern in cases where monitoring stations are remote from transmission lines.

The objectives of the field studies are to study the environmental conditions at selected transmission line sites where transmission line corrosion has been severe and/or conductor samples have been analyzed [1], and, more important, to compare the data collected with those available through the Ontario Ministry of Environment, Atmospheric Environment Service, etc. The results of these studies

will be used to identify criteria for selection of appropriate monitoring stations for the transmission lines of interest when there are more than one close-by stations, and to provide a database for evaluation of future dispersion modelling studies which will allow prediction of pollutant levels in the vicinity of sources and in areas remote from environmental monitoring stations.

This report presents the results of field studies, and compares the data compiled in this study to those obtained from the environmental database for Southern Ontario [2]. This work will provide a starting point for a more detailed follow-up study, which will be conducted once air quality data collected through the Air Quality Monitoring (AQM) and the Acidic Precipitation in Ontario Study (APIOS) by the Ontario Ministry of the Environment, and meteorological data through the Canadian Climate Centre of AES are available for the period, August to November, 1989.

2.0 FIELD STUDIES

Environmental conditions (meteorology, air quality, precipitation/fog, aerosol chemistry) were measured at four sites-Etobicoke (Ontario Hydro Kipling Complex, KX), Port Colborne, Guelph and Smiths Falls over time periods of approximately 2 weeks from August to November, 1989. These sites were selected because they represented diverse environments and conductor samples from transmission lines in these areas were available for analysis. The locations of these sites are indicated in Figure 1. In general terms, the four sites can be classified as rural (Smiths Falls), urban (Etobicoke), and industrial (Guelph and Port Colborne). An outline of the field program and a brief description of the sites were given in a previous report [4]. In summary, the air quality monitoring equipment consisted of a Hiac/Royco 5300H aerosol monitor, high volume sampler , filter pack containing 3 filters (nylon, Teflon and K_2CO_3 impregnated cellulose), Sangamo precipitation collector, tipping bucket rain gauge and active fog water collector. The meteorological equipment consisted of a 10 m meteorological tower, Rotronics temperature/RH sensor and R.M. Young wind monitor. Figure 2 shows the equipment setup at the Etobicoke site. Similar setups were established at each of the sites. The following sections present results from the field studies, which can be grouped under Air Quality Data and Meteorological Data.

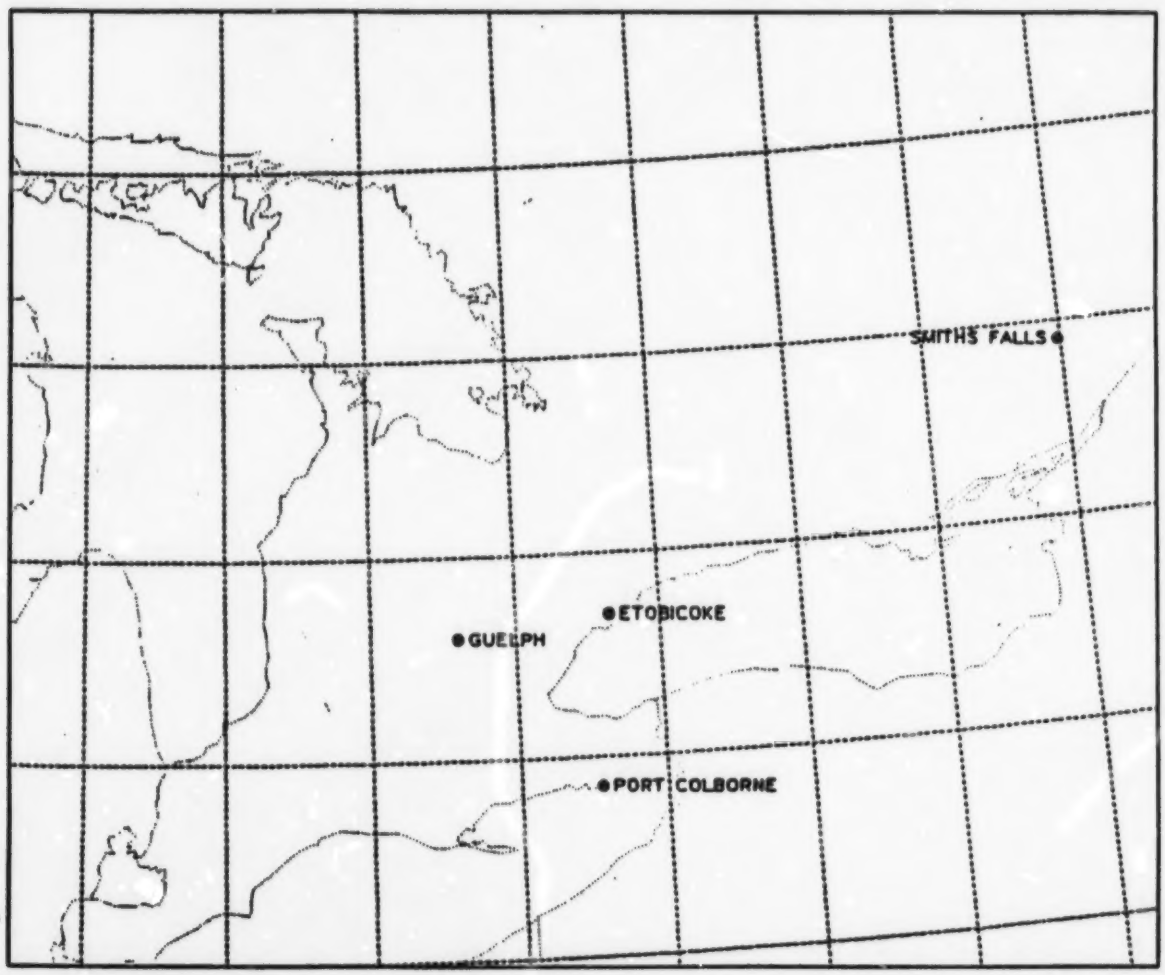

FIGURE 1

LOCATION OF FIELD SITES -
ETOBICOKE, PORT COLBORNE, GUELPH, SMITHS FALLS

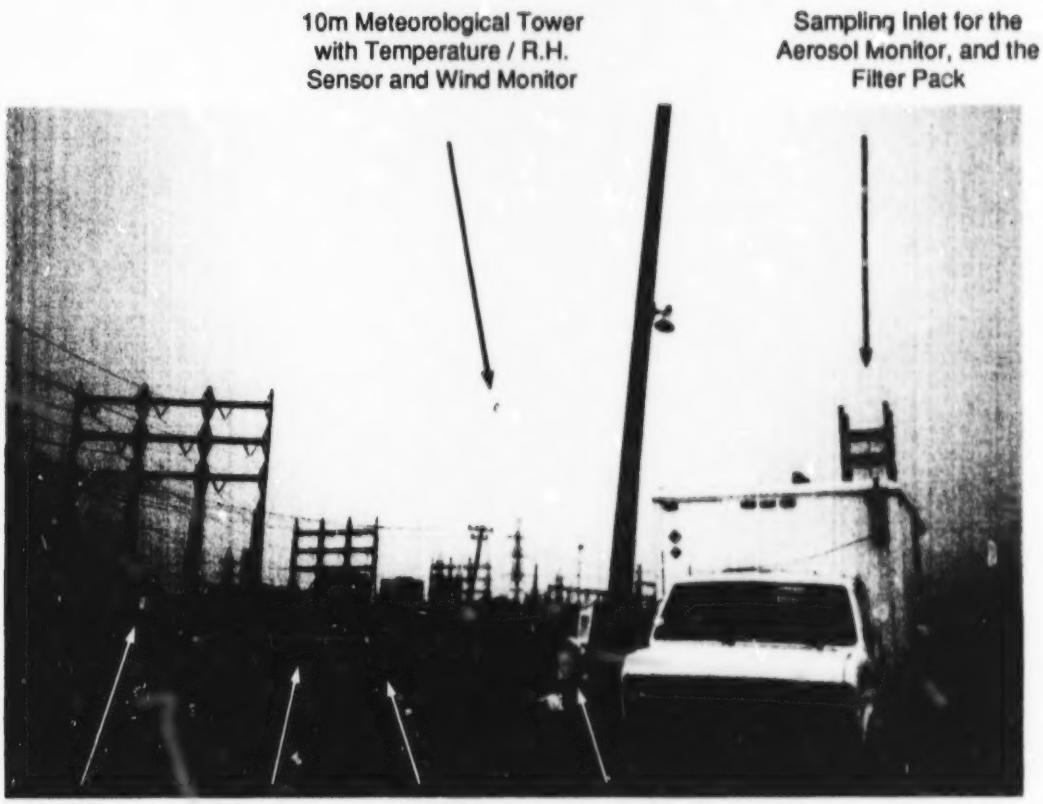
10m Meteorological Tower with Temperature / R.H. Sensor and Wind Monitor
Sampling Inlet for the Aerosol Monitor, and the Filter Pack
Tipping Bucket Rain Gauge
Sangamo Precipitation Collector
Active Fog Collector
Hi-vol Sampler

FIGURE 2

EQUIPMENT SET-UP AT ETOBICOKE (KX)

2.1 Air Quality Data

Air quality parameters: particle concentration and size, particle chemistry, SO_2 concentration in air and precipitation/fog chemistry, were measured at the four sites, and averaged over the study period. Detailed results are given in the Appendix.

2.1.1 Suspended Particles

The particle size and number concentration were measured continuously by the Hiac/Royco 5300H aerosol monitor, which provides six channels of size information at preset thresholds (0.5, 1.5, 3.0, 5.0, 10.0 and 15.0 µm). The sampling time varied from 1.5 to 5 min depending on the particle concentration. The sample interval was kept constant at 13 min. Average values of particle number concentrations and cumulative number distributions for the four sites are given in Table 1. The value of the number median diameter was found to be between 0.5 and 1.5 µm, and did not seem to vary significantly from site to site. On the other hand, number concentrations differed significantly, with the highest level in Guelph and the lowest in Smiths Falls. Measurements of total suspended particulate matter by the hi-volume sampler are given in Table 2. Similar to number concentrations, mass concentrations were highest in Guelph and lowest in Smiths Falls.

TABLE 1

SUSPENDED PARTICLES

Average Number Concentration and Size Measurements (µm)

Site	Number Concentration (#/cm³)	Cumulative Number Distribution (fraction) 0.5	1.5	3	5	10	15
Etobicoke	33.82	1.000	0.310	0.014	0.002	0.000	0.000
Port Colborne	14.99	1.000	0.234	0.011	0.002	0.000	0.000
Guelph	54.37	1.000	0.273	0.028	0.006	0.001	0.000
Smiths Falls	2.87	1.000	0.170	0.006	0.001	0.000	0.000

TABLE 2

AVERAGE TOTAL SUSPENDED PARTICULATE (TSP) MASS CONCENTRATION

Site	Mass Concentration ($\mu g/m^3$) Average	Std. Dev.	No. Samples
Etobicoke	73.06	27.98	7
Port Colborne	49.25	24.77	12
Guelph	128.74	98.63	16
Smiths Falls	33.71	7.94	10

The particles collected on the Teflon filter from the filter pack were analyzed for NH_4^+, Ca^{2+}, Mg^{2+}, Na^+, K^+, Pb, SO_4^{2-}, Cl^- and NO_3^- (Ni, Co for Port Colborne samples only), see Table 3. The Guelph samples showed the highest concentrations of all species, except Pb. In contrast, the Smiths Falls samples showed the lowest concentrations of all species, except Pb.

Amongst the ionic species, sulphates and chlorides have been identified as the most aggressive species in corrosion of aluminum and zinc. The presence of these two ions was also confirmed in the corrosion layers of zinc and aluminum strands of Guelph and Port Colborne conductor samples [1]. The high concentrations of particulate matter observed in Guelph may result from local activities. Most notable are nearby Guelph Dolime Ltd. (calcium and magnesium carbonate), Guelph Municipal Sewage Treatment Plant, Fiberglas Canada Inc (synthetic fibres), Alcan Ingot Alloys, and Hart Chemical Ltd.

2.1.2 SO_2 in Air

The K_2CO_3 impregnated cellulose filters from the filter packs were analyzed for SO_4^{2-} content. The results were expressed as SO_2 concentrations in air (Table 4). There were a few significant differences in concentration among the four sites. Port Colborne showed the highest SO_2 concentrations, which may result in part from local emissions, and in part from sources across the US/Canada border. Smiths Falls, on the other hand, had the lowest SO_2 concentrations.

TABLE 3

COMPOSITION OF SUSPENDED PARTICLES ($\mu g/m^3$)

Chemical Species	Site	AVG	STD	MAX	MIN	NO.
NH^{4+}	Etobicoke(KX)	2.22	2.46	7.44	0.32	7
	Port Colborne	2.09	1.53	5.88	0.35	13
	Guelph	3.67	1.58	5.66	0.67	7
	Smith Falls	1.29	1.26	4.90	0.20	11
Ca^{2+}	Etobicoke(KX)	3.05	1.48	6.30	1.62	7
	Port Colborne	1.01	0.49	1.92	0.31	13
	Guelph	7.63	2.86	12.40	1.97	7
	Smith Falls	0.30	0.10	0.48	0.16	11
Mg^{2+}	Etobicoke(KX)	0.73	0.42	1.62	0.34	7
	Port Colborne	0.36	0.20	0.75	0.11	13
	Guelph	3.32	1.33	5.38	0.92	7
	Smith Falls	0.09	0.04	0.20	0.04	11
Na^{+}	Etobicoke(KX)	0.20	0.08	0.29	0.04	7
	Port Colborne	0.29	0.34	1.21	0.03	13
	Guelph	0.43	0.21	0.83	0.15	7
	Smith Falls	0.12	0.07	0.23	0.03	11
K^{+}	Etobicoke(KX)	0.17	0.07	0.28	0.08	7
	Port Colborne	0.09	0.02	0.12	0.05	13
	Guelph	0.34	0.09	0.47	0.17	7
	Smith Falls	0.05	0.01	0.07	0.05	11
Pb	Etobicoke(KX)	0.17	0.02	0.21	0.14	7
	Port Colborne	0.16	0.01	0.18	0.15	13
	Guelph	0.18	0.03	0.25	0.15	7
	Smith Falls	0.27	0.07	0.34	0.27	11
SO_4^{2-}	Etobicoke(KX)	6.67	7.19	22.29	1.07	7
	Port Colborne	8.63	7.13	22.87	1.28	13
	Guelph	15.36	5.78	22.45	3.43	7
	Smith Falls	1.94	1.44	5.30	1.94	11
Cl^{-}	Etobicoke(KX)	0.39	0.12	0.64	0.25	7
	Port Colborne	0.38	0.19	0.85	0.11	13
	Guelph	1.09	0.55	2.07	0.41	7
	Smith Falls	0.22	0.08	0.35	0.22	11
NO_3^{-}	Etobicoke(KX)	2.23	2.31	7.39	0.44	7
	Port Colborne	1.27	0.73	2.36	0.31	13
	Guelph	8.59	2.81	13.70	4.18	7
	Smith Falls	1.20	0.71	2.81	1.20	11
Ni	Port Colborne	0.31	0.51	1.86	0.07	13
Co	Port Colborne	0.08	0.00	0.09	0.07	13

TABLE 4

SO_2 CONCENTRATION IN AIR

SO_2 (ppb vol)	AVG	STD	MAX	MIN	NO.
Etobicoke (KX)	3.95	3.50	11.69	1.36	6
Port Colborne	8.15	10.11	37.14	0.39	13
Guelph	3.61	2.65	8.54	0.46	6
Smith Falls	0.87	0.44	1.61	0.04	11

2.1.3 Precipitation

The precipitation samples collected with the Sangamo precipitation collector were analyzed for SO_4^{2-}, Cl^-, NO_3^-, NH_4^+, Ca^{2+}, Na^+, Mg^{2+} and K^+. In addition to these analyses, H^+ concentration and conductivity measurements were also taken (Table 5). It is believed that SO_4^{2-} and Cl^- participate in the corrosion of transmission line conductors by adsorbing to oxide-covered aluminum surfaces and by chemical reaction with dissolved zinc salts. Acidity enhances corrosion by dissolving the passivating corrosion product layers such as zinc carbonates [5,6]. In general, the Etobicoke samples had the highest concentrations of SO_4^{2-}, NO_3^-, NH_4^+ and Mg^{2+}, and were more acidic (average H^+ concentration was 108.98 µmoles/L corresponding to the pH of 3.96). The Port Colborne samples showed the highest concentrations of Cl^-, and were more conductive. Precipitation samples from Smiths Falls, on the other hand, had the lowest concentrations of SO_4^{2-}, NO_3^-, and NH_4^+, and were least acidic (average H^+ concentration was 37.16 µmoles/L corresponding to the pH of 4.43) and conductive.

The amount of precipitation was measured by means of a tipping bucket rain gauge, over a period of approximately 2 weeks at each of the four sites (Table 6). Precipitation at a moderate level, enhances corrosion of line conductors by providing moisture and dissolving passive films, but in large amount, it has an opposite effect by washing away corrosive species.

TABLE 5

PRECIPITATION CHEMISTRY

Chemical Species	Site	AVG	STD	MAX	MIN	NO.
SO_4^{2-} (mg/L)	Etobicoke (KX)	9.35	4.18	15.69	5.15	5
	Port Colborne	8.34	8.53	30.25	2.57	8
	Guelph	3.30	1.13	4.98	1.85	4
	Smith Falls	2.45	1.41	5.28	0.51	9
Cl^- (mg/L)	Etobicoke (KX)	0.57	0.48	1.47	0.08	5
	Port Colborne	0.66	0.45	1.76	0.33	8
	Guelph	0.34	0.04	0.39	0.27	4
	Smith Falls	0.41	0.19	0.83	0.22	9
NO_3^- (mg/L)	Etobicoke (KX)	6.25	3.40	12.68	2.92	5
	Port Colborne	3.88	2.70	9.98	1.66	8
	Guelph	3.39	2.30	7.08	0.81	4
	Smith Falls	3.09	1.80	5.41	0.51	9
NH_4^+ (mg/L)	Etobicoke (KX)	1.28	0.44	1.89	0.86	5
	Port Colborne	0.63	0.43	1.54	0.20	8
	Guelph	0.61	0.41	1.11	0.19	4
	Smith Falls	0.47	0.45	1.42	0.04	9
Ca^{2+} (mg/L)	Etobicoke (KX)	1.29	1.05	3.30	0.45	5
	Port Colborne	0.59	0.73	2.45	0.07	8
	Guelph	0.59	0.22	0.84	0.26	4
	Smith Falls	0.69	0.98	3.30	0.05	9
Na^+ (mg/L)	Etobicoke (KX)	0.05	0.04	0.13	0.02	5
	Port Colborne	0.05	0.03	0.09	0.02	8
	Guelph	0.03	0.02	0.07	0.02	4
	Smith Falls	0.14	0.06	0.29	0.07	9
Mg^{2+} (mg/L)	Etobicoke (KX)	0.39	0.37	1.11	0.09	5
	Port Colborne	0.16	0.22	0.73	0.02	8
	Guelph	0.23	0.14	0.46	0.10	4
	Smith Falls	0.18	0.33	1.10	0.02	9
K^+ (mg/L)	Etobicoke (KX)	0.04	0.01	0.06	0.02	5
	Port Colborne	0.02	0.01	0.05	0.02	8
	Guelph	0.02	0.00	0.02	0.02	4
	Smith Falls	0.04	0.02	0.08	0.02	9
H^+ (µmoles/L)	Etobicoke (KX)	108.98	22.09	125.89	79.43	4
	Port Colborne	66.42	37.19	120.23	5.01	7
	Guelph	45.76	32.96	95.50	11.22	4
	Smith Falls	37.16	32.68	87.10	0.59	9
Conductivity (µS/cm)	Etobicoke (KX)	69.68	38.01	119.30	15.70	5
	Port Colborne	86.73	92.01	324.00	17.70	8
	Guelph	30.33	15.60	52.00	13.90	4
	Smith Falls	27.16	17.72	57.80	5.09	9

TABLE 6

PRECIPITATION INTENSITY

Site	Date (1989)	Intensity (mm)
Etobicoke (KX)	Aug 15	8.4
	Aug 21	10.8
	Aug 22	6.0
	Total	25.2
Port Colborne	Sept 1	14.50
	Sept 6	0.25
	Sept 7	0.25
	Sept 9	3.00
	Sept 14	7.25
	Total	25.25
Smiths Falls	Nov 5	1.50
	Nov 6	2.25
	Nov 7	2.25
	Nov 8	3.25
	Nov 9	1.25
	Nov 11	0.50
	Nov 13	3.50
	Nov 14	6.75
	Nov 15	2.00
	Nov 16	5.25
	Total	28.50

*Amount of precipitation was not registered in Guelph during the period from Oct 23 to Oct 30, 1989

2.1.4 Fog Chemistry

Fog samples were obtained by the active fog water collector in Guelph only (there were no fog events at the other sites). Similar to precipitation, fog enhances corrosion by delivering moisture and corrosive species to the metal surfaces. Fog water is generally more acidic than rain water [7], but the Guelph fog samples were alkaline and contained unusually high concentrations of Ca^{2+} and Mg^{2+} (Table 7). It appears that local dust particles are acting as

condensation nuclei for fog droplets. Alternatively, the alkaline dust may be collected along with fog droplets, by the active fog water collector.

TABLE 7

FOG CHEMISTRY

Guelph	Oct 14-15	Oct 16-17	Oct 17-18	Oct 24-25
NH_4^+ (mg/L)	0.17	0.37	0.03	8.6
Na^+ (mg/L)	2.0	0.51	0.36	0.76
Ca^{2+} (mg/L)	171.0	-	-	-
Mg^{2+} (mg/L)	100.0	-	-	-
K^+ (mg/L)	1.3	0.41	0.18	0.39
NO_3^- (mg/L)	89.4	4.24	2.8	40.1
SO_4^{2-} (mg/L)	50.5	7.11	5.03	47.5
Cl^- (mg/L)	10.3	1.3	0.18	1.9
F^- (mg/L)	<0.5	<0.5	<0.5	<0.5
H^+ (µmoles/L)	0.000017	-	-	0.03
pH	10.77	-	-	7.48
Conductivity (µS/cm)	464.0	63.6	46.1	326.0
Amount of Sample (g)	80.93	74.73	85.53	342.86

2.2 Meteorological Data

The meteorological parameters: temperature, relative humidity and wind speed and direction, were determined every 10 s and stored in a Campbell data logger as 10 min averages. The parameters were averaged over the study period for each of the sites (Table 8). Details are given in the Appendix.

Table 8

METEOROLOGICAL DATA

Site		Wind Speed (m/s)	Wind Direction (degree)	Temperature (°C)	Relative Humidity (%)
Etobicoke	Average	1.99	190.48	19.67	70.35
	Std. Dev.	0.63	38.53	1.65	9.74
Port Colborne	Average	2.66	167.70	18.74	77.73
	Std. Dev.	0.74	67.35	3.26	9.21
Guelph	Average	0.96	158.20	11.11	78.76
	Std. Dev.	0.33	26.24	0.94	7.71
Smiths Falls	Average	3.37	195.18	3.07	76.79
	Std. Dev.	1.37	69.58	3.73	13.45

2.2.1 Temperature

Temperature has an interesting effect on transmission line corrosion. Increasing temperature enhances corrosion by increasing the conductivity and surface tension of the liquid film and increasing the rate of reaction. Elevated temperatures also concentrate ions by evaporation to the extent that corrosion is inhibited due to loss of moisture. Table 8 shows the average values measured by the Rotronics temperature sensor for the four sites. During the sampling periods, the season changed from summer (temperatures in Etobicoke and Port Colborne were about 20°C), to fall (temperature in Guelph was about 10°C) and ended in early winter (temperature in Smiths Falls dropped to about 3.0°C).

2.2.2 Relative Humidity

Relative humidity was measured by the Rotronics RH sensor. Table 8 shows the average values of relative humidity at the four sites. The average relative humidity was high, about 75% for all sites. The amount of moisture on the conductors is related to the ambient relative humidity and the presence of hygroscopic deposits, which may lead to atmospheric corrosion of conductors at and above a critical relative humidity of about 85%.

2.2.3 Wind Speed and Direction

Wind speed and direction were registered by the R.M. Young wind monitor. The wind speed averaged about 2.0 m/s in Etobicoke, 2.7 m/s in Port Colborne, 1.0 m/s in Guelph, and 3.4 m/s in Smiths Falls (Table 8). Southwesterly and southern winds prevailed at the four sites, with occasional northeasterly wind in Port Colborne and Smiths Falls. The transport of pollutants from source to conductors is governed by wind speed and direction. Furthermore, wind speed has a drying effect on the wet conductor, and modifies the surface temperature of the conductor.

3.0 PRELIMINARY COMPARISON WITH ENVIRONMENTAL DATA BASE

Values of key environmental parameters (SO_4^{2-}, Cl^-, NH_4^+ in precipitation; Ca in suspended particles; SO_2 in air) , averaged over periods of approximately 2 weeks at the four sites, are summarized in Table 9. The values are higher in Port Colborne and Etobicoke, and lower in Smiths Falls. A previous report documented the geographical distributions of air pollutant levels over southern Ontario [3]. These isopleths of key environmental parameters are compared to the averaged values obtained in this study in Figures 3-7. In general, the results from the field studies support the overall trend of high pollutant concentrations in the Toronto/ Hamilton area and the southwestern region, and low concentrations in northern and eastern Ontario. The absolute values obtained from the field studies, however, differ from those presented in the isopleths, especially over the Port Colborne site, for several reasons. Firstly, the data used to generate the isopleths represent average values over the past twenty years, whereas the data collected during the field studies represent recent short-term conditions. Secondly, the APIOS and AQM monitoring stations are remote from the transmission lines of interest located in Etobicoke, Guelph and Smiths Fall. Furthermore, there is no SO_2 monitoring and APIOS stations near the Port Colborne site. Thirdly, contour values depend on the resolution of the virtual grid and the interpolation method used in the analysis, especially in the case of sparse data (eg, near the Port Colborne and Niagara Falls areas). More complete environmental data, especially over the Port Colborne/Niagara Falls area, are needed for fine-tuning of the isopleths.

TABLE 9

KEY ENVIRONMENTAL PARAMETERS

	Etobicoke	Port Colborne	Guelph	Smiths Falls	Threshold Value***
SO_4^{2-} (mg/L)*	9.35	8.34	3.30	2.45	4.1
Cl^- (mg/L)*	0.57	0.66	0.34	0.41	0.33
NH_4^+(mg/L)*	1.28	0.63	0.61	0.47	0.59
SO_2 (ppb)	3.95	8.15	3.61	0.87	4.9
Ca^{2+} ($\mu g/m^3$)**	3.05	1.01	7.63	0.30	0.74
Corrosion Index	5	5	3	1	

* Precipitation
** Suspended particles
*** Reference from [2]

An environmental corrosion index has been developed to rate the atmospheric corrosivity of locations across Ontario [2]. The algorithm arrives at an index rating (1-5) by comparing successively key environmental parameters with threshold levels. A high index rating indicates severe atmospheric corrosivity of the location, while a value of one represents a rather clean environment. Environmental corrosion indices for the southern Ontario region are displayed in Figure 8. Based on the algorithm developed in reference [2], the following environmental corrosion indices are derived: 5 for Etobicoke and Port Colborne, 3 for Guelph, and 1 for Smiths Falls. (Total yearly precipitation is assumed to be less than 820 mm). These are displayed in Figure 8 as well. The results from the field studies support previous findings that the Toronto/ Hamilton area and the south western region are very corrosive, and north eastern Ontario is mildly-corrosive.

4.0 SUMMARY

A short-term field study has been completed; it included the collection of air quality data (suspended particle concentration, size and chemistry, SO_2 concentration in air, and precipitation/fog chemistry), and meteorological data (temperature, relative humidity, wind speed and direction) at sites in Etobicoke, Port Colborne, Guelph and Smiths Falls. In general, the pollutant levels are higher in Port Colborne and Etobicoke, and lower in Smiths Falls.

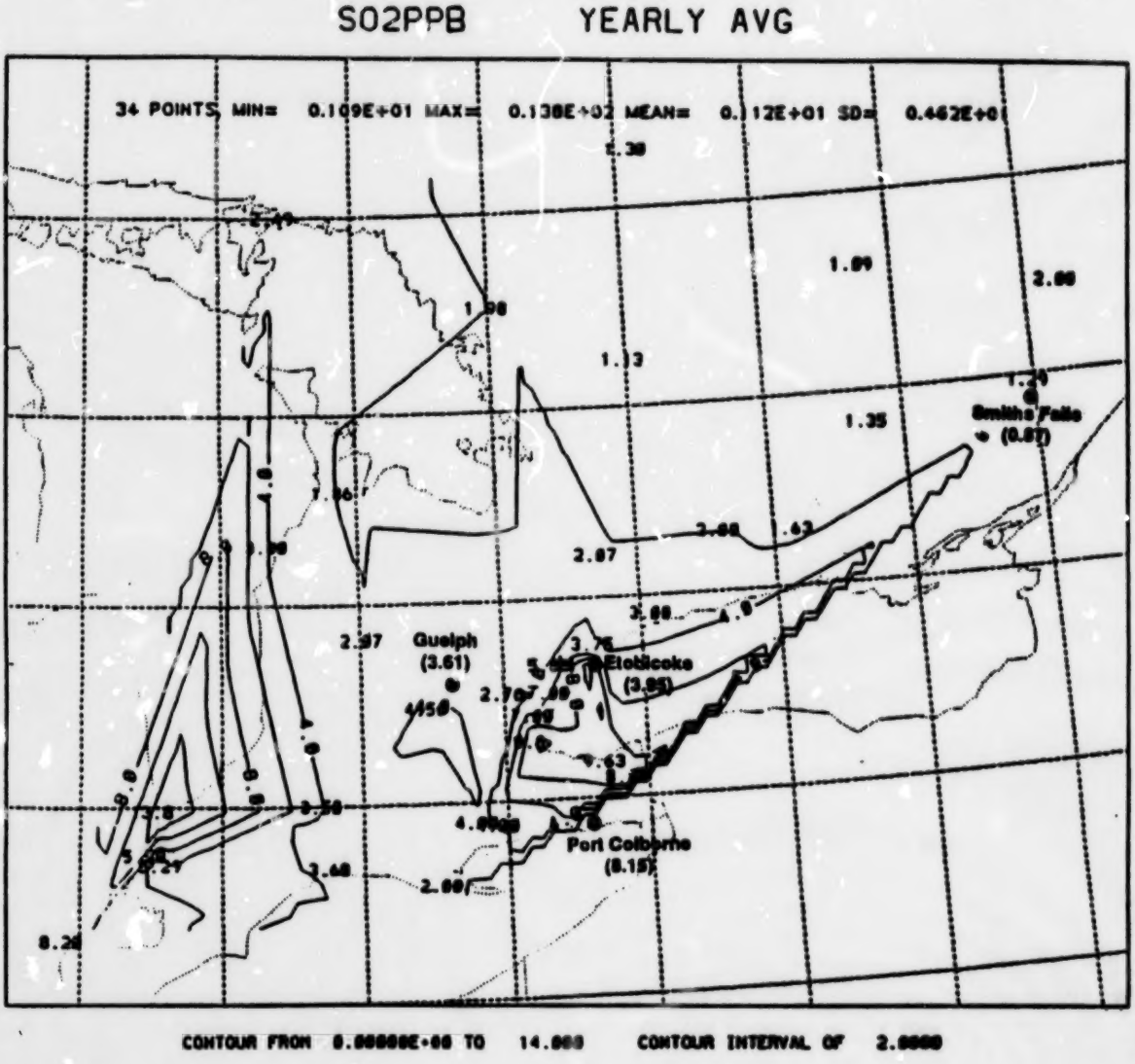

FIGURE 3

CONTOUR LINES OF YEARLY AVERAGE SO_2 CONCENTRATIONS IN AIR (ppb)

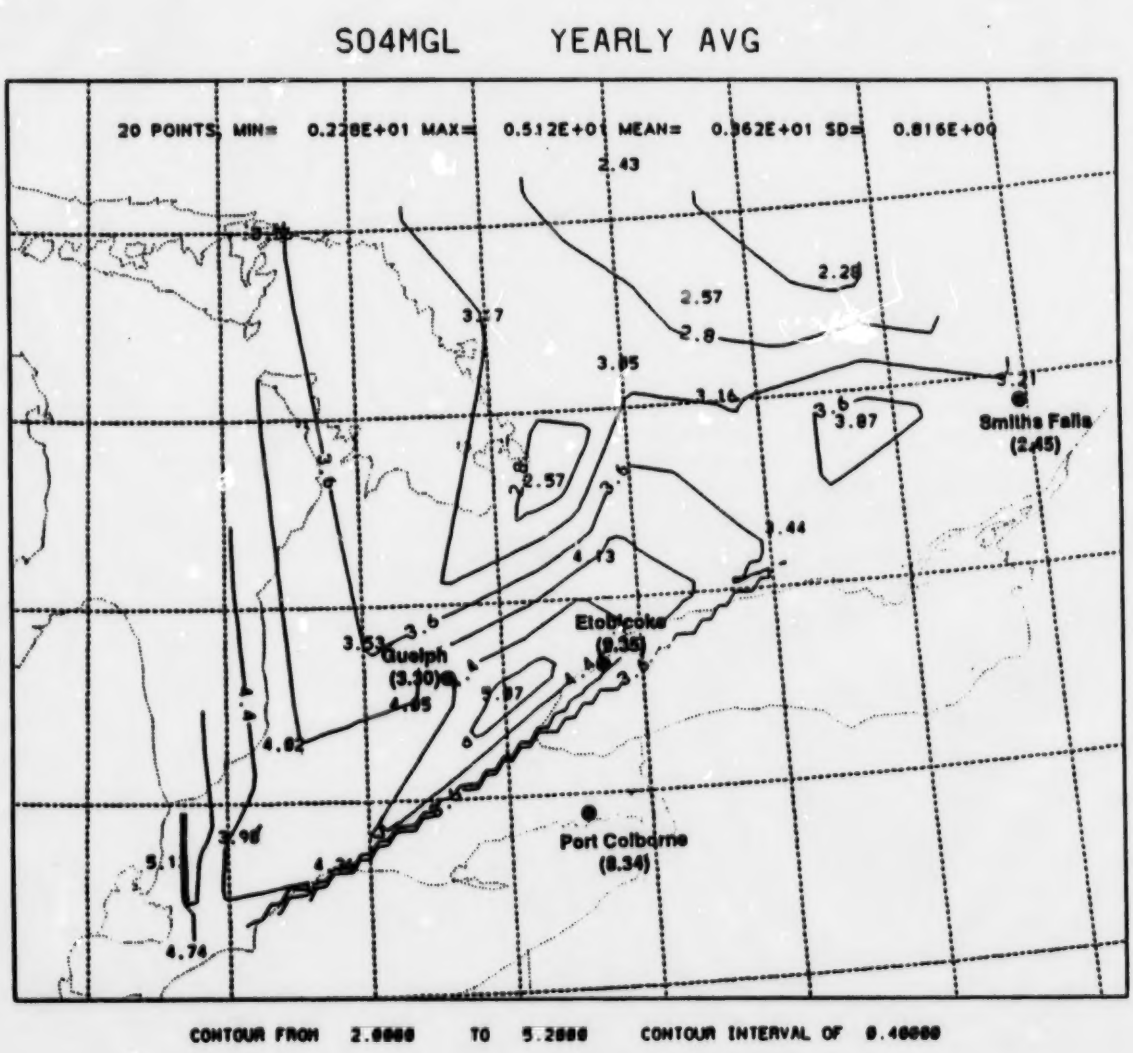

FIGURE 4

CONTOUR LINES OF YEARLY AVERAGE SULPHATE CONCENTRATIONS IN PRECIPITATION (mg/L)

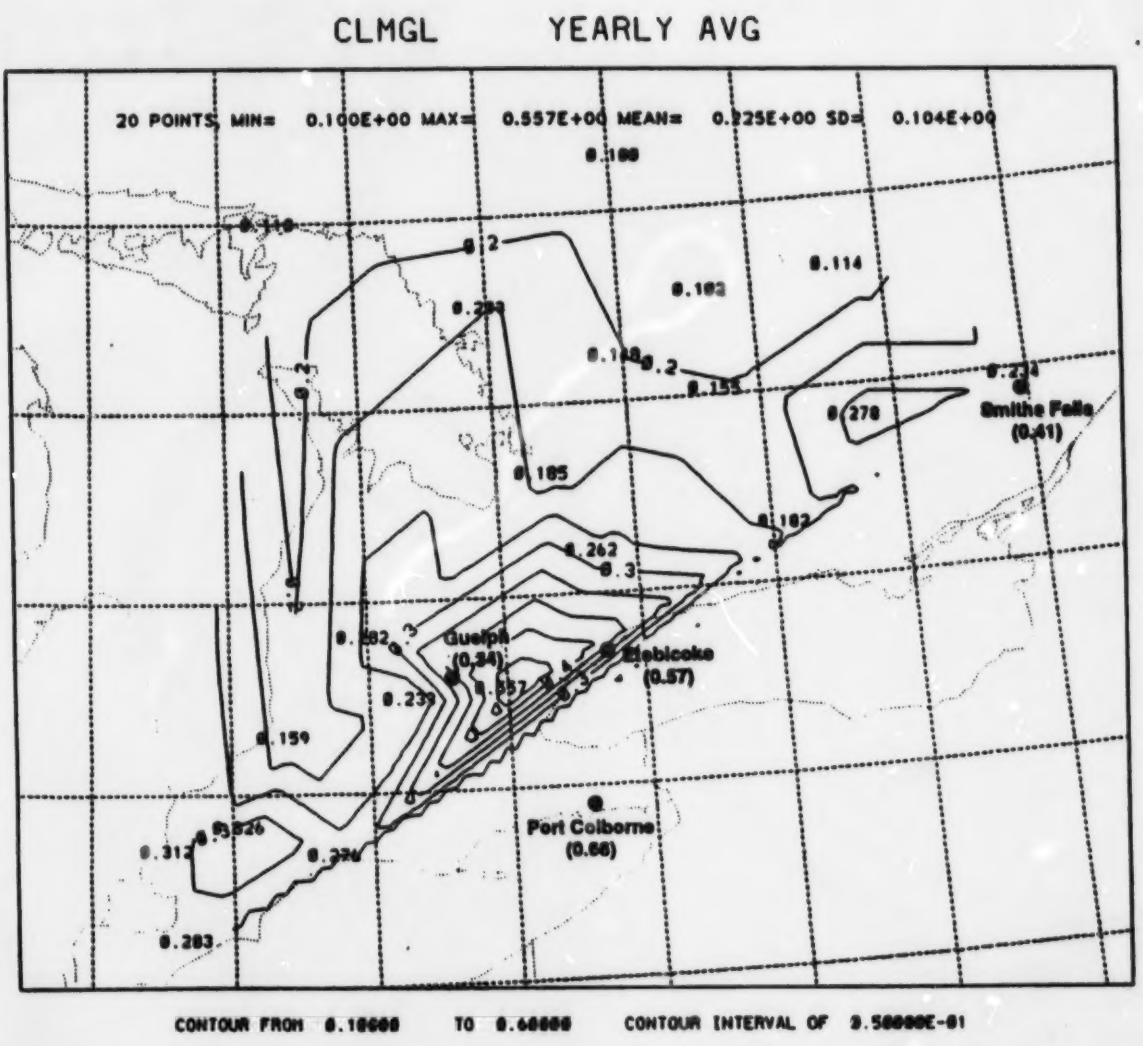

FIGURE 5

CONTOUR LINES OF YEARLY AVERAGE CHLORIDE CONCENTRATIONS IN PRECIPITATION (mg/L)

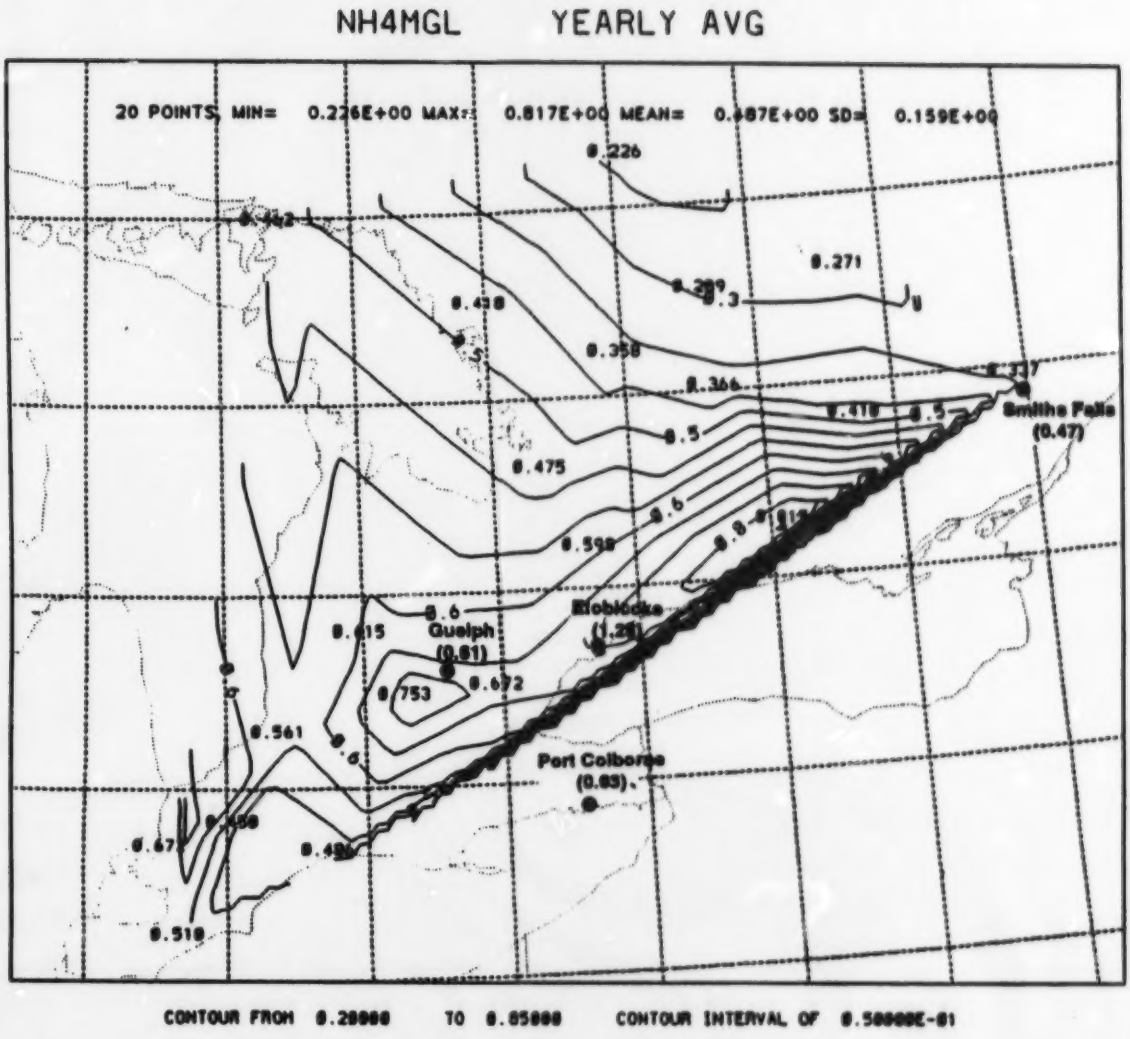

FIGURE 6

CONTOUR LINES OF YEARLY AVERAGE AMMONIA CONCENTRATIONS IN PRECIPITATION (mg/L)

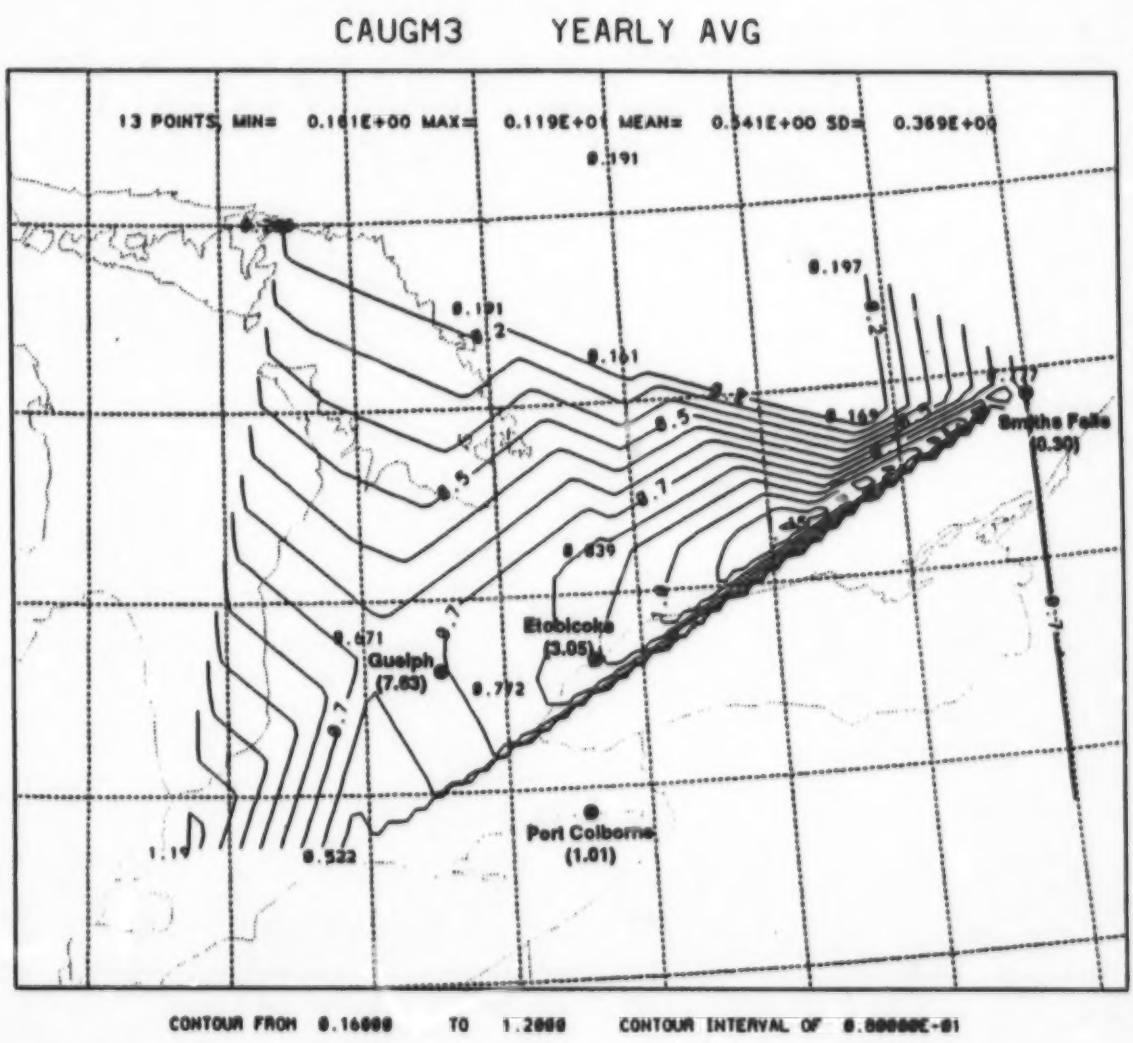

FIGURE 7

CONTOUR LINES OF YEARLY AVERAGE CALCIUM CONCENTRATIONS IN AIR ($\mu g/m^3$)

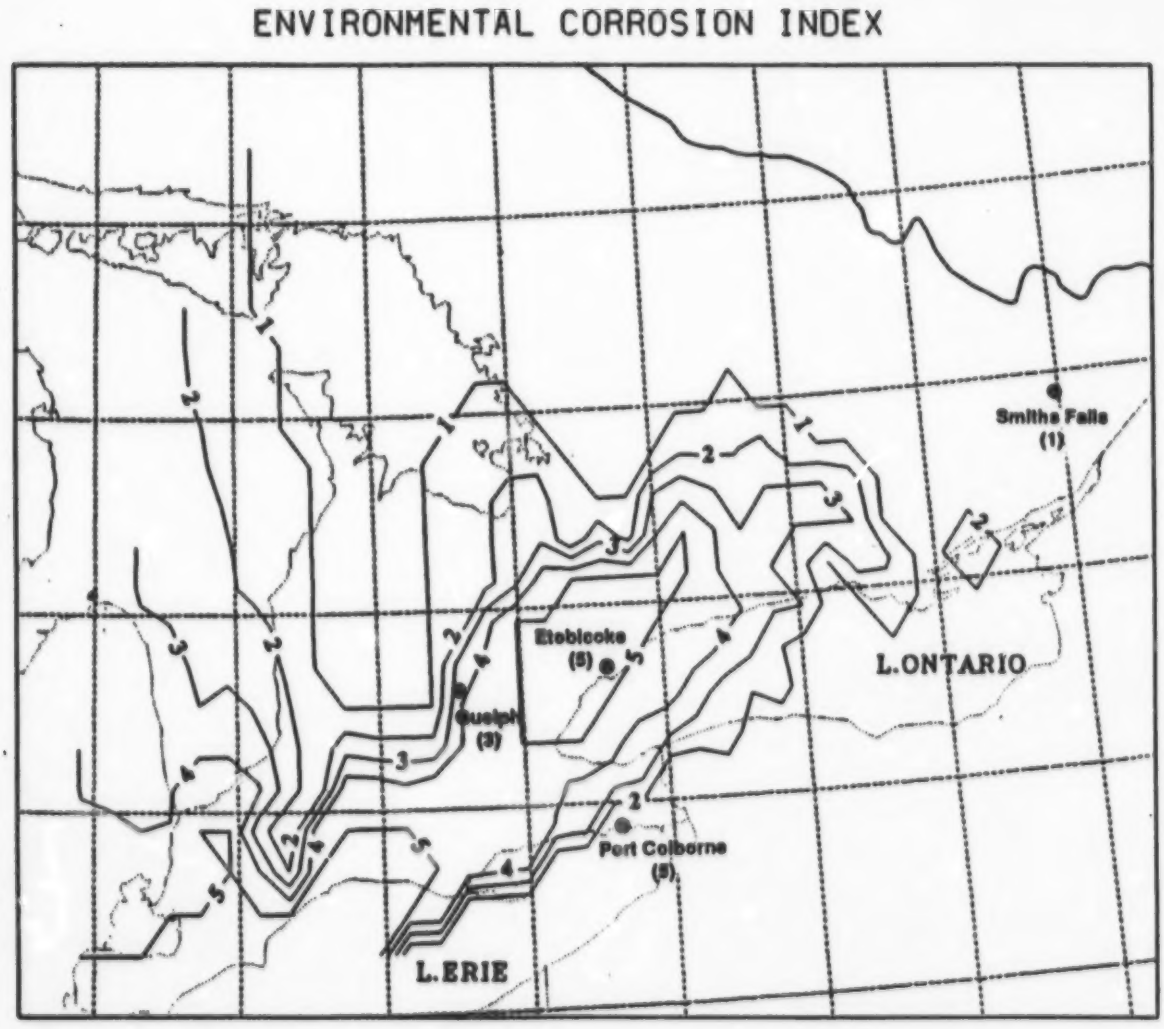

FIGURE 8

ENVIRONMENTAL CORROSION INDICES OVER ONTARIO REGION

A preliminary comparison with isopleths of key environmental parameters (SO_4^{2-}, Cl^-, NH_4^+ in precipitation; SO_2 in air; Ca in suspended particles) over southern Ontario supports the general trend of high pollutant levels in the Toronto/Hamilton area and the south western region, and low levels over north eastern Ontario. However, there are a few differences between the absolute values of key parameters as measured in this study and the corresponding values determined from the isopleths. Differences may be attributed to long term variability in pollutant concentration, different study periods, and an incomplete data base in plotting the isopleths.

Environmental corrosion index ratings have been determined for Etobicoke, Port Colborne, Guelph and Smiths Falls. Severe atmospheric corrosivities are indicated in Etobicoke and Port Colborne, median corrosivity in Guelph, and low corrosivity in Smiths Falls. These findings support the general trend of pollutant levels.

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APPENDIX

APPENDIX

Table A1. Particle Number Concentration and Size Measurements (um)

Site	Date (1989)	Concentration (#/cm3)	Cumulative Number Distribution 0.5	1.5	3	5	10	15	Cumulative Number Distribution (fraction) 0.5	1.5	3	5	10	15
Etobicoke (XX)														
	Aug 8	1.68	23739.3	7493.3	1046.0	172.3	14.8	0.4	1.000	0.324	0.044	0.007	0.001	0.000
	Aug 11	26.88	380567.0	34457.4	2011.1	392.6	21.4	0.5	1.000	0.091	0.005	0.001	0.000	0.000
	Aug 14	56.82	321837.5	84969.8	1438.3	253.7	11.4	0.3	1.000	0.264	0.004	0.001	0.000	0.000
	Aug 15	96.34	549085.9	322231.8	6186.6	787.5	47.0	0.7	1.000	0.589	0.011	0.001	0.000	0.000
	Aug 16	5.20	29471.9	7010.2	455.9	105.4	7.3	0.2	1.000	0.238	0.015	0.004	0.000	0.000
	Aug 17	8.74	49522.7	14621.9	954.3	249.9	14.4	0.4	1.000	0.295	0.019	0.005	0.000	0.000
	Aug 18	26.01	147311.3	41495.8	3283.2	547.6	40.6	0.8	1.000	0.282	0.022	0.004	0.000	0.000
	Aug 19	83.33	471953.9	107365.6	12932.6	909.0	70.5	1.7	1.000	0.227	0.027	0.002	0.000	0.000
	Aug 23	15.02	85059.2	19707.3	739.6	178.8	9.6	0.3	1.000	0.232	0.009	0.002	0.000	0.000
	Aug 24	17.53	99301.9	28092.0	1273.7	349.0	17.6	0.3	1.000	0.283	0.013	0.004	0.000	0.000
	Average	33.82	215785.1	66864.5	3032.1	394.6	25.4	0.6	1.000	0.310	0.014	0.002	0.000	0.000
	Std.Dev	30.41	178299.0	86826.0	3501.5	245.9	18.6	0.4	0.000	0.113	0.011	0.002	0.000	0.000
Port Colborne														
	Aug 30	0.81	4600.2	1491.7	321.3	64.4	5.3	0.3	1.000	0.324	0.070	0.014	0.001	0.000
	Aug 31	1.37	9704.9	2253.0	357.8	75.5	4.8	0.0	1.000	0.232	0.037	0.008	0.000	0.000
	Sep 1	5.97	67628.4	14562.2	511.6	93.5	7.1	0.0	1.000	0.215	0.008	0.001	0.000	0.000
	Sep 2	7.69	87084.4	25444.5	1304.2	313.6	20.6	0.4	1.000	0.292	0.015	0.004	0.000	0.000
	Sep 5	0.83	66042.4	15703.8	1418.5	300.1	19.5	0.5	1.000	0.238	0.021	0.005	0.000	0.000
	Sep 6	24.10	273026.1	72673.9	2253.5	519.9	33.9	0.8	1.000	0.266	0.008	0.002	0.000	0.000
	Sep 7	19.27	218315.5	45447.0	1065.4	187.8	0.7	0.2	1.000	0.208	0.005	0.001	0.000	0.000
	Sep 8	38.65	437772.2	111935.1	4205.5	457.0	36.3	1.0	1.000	0.256	0.010	0.001	0.000	0.000
	Sep 9	32.26	365411.7	75687.5	912.3	182.6	12.7	0.6	1.000	0.207	0.002	0.000	0.000	0.000
	Sep 10	29.08	329386.4	72340.1	2738.7	355.7	32.8	0.8	1.000	0.220	0.008	0.001	0.000	0.000
	Sep 11	34.78	394020.2	59547.7	5806.9	699.3	58.6	1.1	1.000	0.151	0.015	0.002	0.000	0.000
	Sep 12	2.91	32970.8	6793.5	707.8	137.0	4.6	0.1	1.000	0.206	0.021	0.004	0.000	0.000
	Sep 13	4.14	46935.2	15579.2	1696.2	463.0	25.5	0.6	1.000	0.332	0.036	0.010	0.001	0.000
	Sep 14	5.86	66326.3	18727.0	1181.0	287.6	25.3	0.9	1.000	0.282	0.018	0.004	0.000	0.000
	Sep 15	12.08	136889.8	56030.7	2402.2	365.4	30.2	0.3	1.000	0.409	0.018	0.003	0.000	0.000
	Average	14.99	169074.3	39614.5	1792.2	300.2	21.7	0.5	1.000	0.234	0.011	0.002	0.000	0.000
	Std.Dev	12.53	142608.0	31361.6	1425.7	171.1	14.3	0.3	0.000	0.060	0.016	0.004	0.000	0.000

Table A1 (cont'd)

Site	Date (1989)	Concentration (#/cm3)	Cumulative Number Distribution						Cumulative Number Distribution (fraction)					
			0.5	1.5	3	5	10	15	0.5	1.5	3	5	10	15
Guelph														
	Oct 12	1.85	10287.6	3076.0	457.1	81.7	3.4	0.1	1.000	0.299	0.047	0.009	0.000	0.000
	Oct 13	6.48	36127.7	11886.0	1202.8	232.3	7.6	0.3	1.000	0.329	0.040	0.008	0.000	0.000
	Oct 14	6.54	35200.5	13517.0	1736.4	387.6	12.7	0.3	1.000	0.384	0.055	0.013	0.000	0.000
	Oct 15	52.21	315082.0	108703.3	3439.9	1795.5	836.2	4.8	1.000	0.345	0.012	0.007	0.003	0.000
	Oct 16	67.66	339341.5	80084.6	3095.6	1388.4	614.5	3.9	1.000	0.236	0.010	0.005	0.002	0.000
	Oct 17	7.00	30011.7	5642.2	508.9	69.5	0.1	0.2	1.000	0.188	0.018	0.003	0.000	0.000
	Oct 18	14.60	62005.8	8265.9	716.8	90.3	7.3	0.2	1.000	0.133	0.012	0.001	0.000	0.000
	Oct 19	21.96	93271.3	9020.5	1078.3	220.3	21.7	0.2	1.000	0.097	0.012	0.002	0.000	0.000
	Oct 20	85.29	362310.7	31453.0	2336.4	137.0	14.6	0.2	1.000	0.087	0.006	0.000	0.000	0.000
	Oct 21	139.63	593130.6	67187.6	4894.9	133.1	14.9	0.5	1.000	0.113	0.008	0.000	0.000	0.000
	Oct 22	134.93	573178.9	30224.8	5659.2	404.0	37.0	0.5	1.000	0.053	0.010	0.001	0.000	0.000
	Oct 23	136.34	579152.8	311535.3	120616.0	27830.4	1974.5	361.5	1.000	0.538	0.208	0.048	0.003	0.001
	Oct 24	16.08	68286.8	10769.5	1263.8	529.3	74.7	0.2	1.000	0.158	0.019	0.008	0.001	0.000
	Oct 25	26.22	111400.4	26276.1	2258.1	1307.2	274.1	0.0	1.000	0.236	0.020	0.012	0.002	0.000
	Oct 26	86.42	367112.7	136948.0	4275.2	681.9	66.1	0.0	1.000	0.373	0.012	0.002	0.000	0.000
	Oct 27	87.35	371063.4	197458.9	5304.5	338.3	11.7	0.0	1.000	0.532	0.014	0.001	0.000	0.000
	Oct 28	48.29	205151.9	120456.5	5216.0	1267.4	216.9	0.0	1.000	0.587	0.025	0.006	0.001	0.000
	Oct 29	56.19	238686.8	78840.6	1013.2	99.2	0.9	0.0	1.000	0.330	0.004	0.000	0.000	0.000
	Oct 30	37.91	161026.3	26114.6	742.5	112.1	3.1	0.0	1.000	0.162	0.005	0.001	0.000	0.000
	Average	54.37	239570.0	67234.3	8727.1	1426.6	221.0	19.6	1.000	0.272	0.028	0.006	0.001	0.000
	Std.Dev	45.02	192160.7	78232.2	26430.1	3900.6	469.2	80.6	0.000	0.157	0.045	0.007	0.001	0.000
Smiths Falls														
	Nov 3	0.84	11906.2	2412.1	97.6	17.8	0.8	0.0	1.000	0.203	0.008	0.001	0.000	0.000
	Nov 4	1.14	16126.2	3366.8	113.3	22.1	0.1	0.0	1.000	0.209	0.007	0.001	0.000	0.000
	Nov 5	3.26	46195.1	5342.7	249.3	46.6	2.9	0.1	1.000	0.116	0.005	0.001	0.000	0.000
	Nov 6	4.62	65401.5	7872.8	244.9	36.4	2.0	0.0	1.000	0.120	0.004	0.001	0.000	0.000
	Nov 7	1.02	14436.4	2386.7	135.5	19.5	1.2	0.0	1.000	0.165	0.009	0.001	0.000	0.000
	Nov 8	6.02	85260.0	14059.8	263.5	62.1	13.9	0.0	1.000	0.165	0.003	0.001	0.000	0.000
	Nov 9	4.48	63404.3	9425.7	278.7	50.4	2.9	0.1	1.000	0.149	0.004	0.001	0.000	0.000
	Nov 10	2.02	28641.7	3955.4	233.8	35.5	1.7	0.0	1.000	0.138	0.008	0.001	0.000	0.000
	Nov 11	0.98	13924.0	2118.3	132.6	23.2	1.2	0.0	1.000	0.152	0.010	0.002	0.000	0.000
	Nov 13	2.35	33261.8	5516.5	236.9	42.6	2.3	0.0	1.000	0.166	0.007	0.001	0.000	0.000
	Nov 14	5.42	76793.3	10675.6	255.8	39.2	0.4	0.0	1.000	0.139	0.003	0.001	0.000	0.000
	Nov 15	5.31	75235.7	19762.5	280.7	51.1	5.2	0.0	1.000	0.263	0.004	0.001	0.000	0.000
	Nov 16	2.06	29225.3	5952.7	486.9	98.9	10.1	0.3	1.000	0.204	0.017	0.003	0.000	0.000
	Nov 17	0.72	10259.7	4092.6	670.4	178.8	16.2	0.3	1.000	0.399	0.065	0.017	0.002	0.000
	Average	2.87	40729.8	6924.3	262.9	51.7	4.6	0.1	1.000	0.170	0.006	0.001	0.000	0.000
	Std.Dev	1.86	26370.4	4898.4	146.8	40.6	4.9	0.1	0.000	0.071	0.015	0.004	0.000	0.000

Table A2. Total Suspended Particulate (TSP) Mass Concentration

Site	DATE (1989)	HI-VOL FILTER WEIGHT Before (g)	After (g)	Net (g)	Time (hr)	TSP (ug/m3)
Etobicoke (XX)						
	Aug 9	4.39348	4.55209	0.15861	17.53	133.12
	Aug 15	4.43085	4.48694	0.05609	18.23	45.27
	Aug 16	4.43255	4.50342	0.07087	23.42	44.52
	Aug 17	4.41882	4.51245	0.09363	23.60	58.37
	Aug 18	4.38167	4.50631	0.12464	22.98	79.80
	Aug 22	4.37878	4.49728	0.11850	24.09	72.37
	Aug 23	4.40564	4.52300	0.11736	22.15	77.95
					Average	73.06
					Std. Dev.	27.98
Port Colborne						
	Aug 31	4.4059	4.4972	0.0913	23.08	58.18
	Sep 1	4.4175	4.4372	0.0197	17.76	16.35
	Sep 5	4.4453	4.5685	0.1232	24.04	75.41
	Sep 6	4.4090	4.5527	0.1437	24.06	87.89
	Sep 7	4.4049	4.5128	0.1079	23.96	66.26
	Sep 8	4.3807	4.5110	0.1303	23.89	80.25
	Sep 9	4.4241	4.4926	0.0685	23.98	42.03
	Sep 10	4.3945	4.4255	0.0310	23.90	19.08
	Sep 11	3.3841	3.4624	0.0783	23.92	48.16
	Sep 12	3.3707	3.4317	0.0610	23.93	37.50
	Sep 13	3.3521	3.4358	0.0837	23.92	51.48
	Sep 14	3.3588	3.3723	0.0135	23.59	8.42
					Average	49.25
					Std. Dev.	24.77
Guelph						
	Oct 12	3.36219	3.53465	0.17246	22.60	112.27
	Oct 13	3.35506	3.49491	0.13985	23.46	87.71
	Oct 14	3.35027	3.67985	0.32958	24.09	201.29
	Oct 15	3.32254	3.56234	0.23980	22.00	160.37
	Oct 16	3.36012	3.45228	0.09216	27.05	50.13
	Oct 17	3.36886	3.40818	0.03932	23.98	24.12
	Oct 18	3.38791	3.45104	0.06313	23.48	39.56
	Oct 19	3.36706	3.44412	0.07706	27.49	41.24
	Oct 20	3.38074	3.41389	0.03315	20.31	24.01
	Oct 21	3.36409	3.40017	0.03608	24.22	21.92
	Oct 22	3.35487	3.44554	0.09067	24.10	55.35

Table A2 (cont'd)

Site	DATE (1989)	HI-VOL FILTER WEIGHT Before (g)	After (g)	Net (g)	Time (hr)	TSP (ug/m3)
Guelph						
	Oct 26	3.34766	3.76274	0.41508	18.46	330.82
	Oct 27	3.34493	3.83081	0.48588	24.36	293.46
	Oct 28	3.32165	3.70793	0.38628	24.47	232.25
	Oct 29	3.36417	3.69139	0.32722	24.25	198.53
	Oct 30	3.33430	3.61959	0.28529	22.47	186.80
					Average	128.74
					Std. Dev.	98.63
Smiths Falls						
	Nov 6	3.34639	3.38218	0.03579	24.20	21.76
	Nov 7	3.31855	3.36463	0.04608	23.22	29.20
	Nov 8	3.31890	3.38510	0.06620	23.46	41.52
	Nov 9	3.31654	3.38458	0.06804	22.88	43.75
	Nov 10	3.36064	3.41083	0.05019	21.32	34.64
	Nov 11	3.30048	3.35853	0.05805	24.93	34.26
	Nov 12	3.34640	3.39246	0.04606	23.51	28.82
	Nov 13	3.32968	3.40272	0.07304	23.86	45.04
	Nov 14	3.32287	3.38210	0.05923	23.91	36.45
	Nov 16	3.33662	3.37111	0.03449	23.42	21.67
					Average	33.71
					Std. Dev.	7.94

Flow rate = 18.88 L/s (40 CFM)

Table A3. Composition of Suspended Particles (ug/m3)

Etobicoke(XX)	Aug 14	Aug 15	Aug 16	Aug 17	Aug 18	Aug 22	Aug 23
NH_4^+	7.44	4.23	0.76	0.32	0.62	1.27	0.86
Ca^{2+}	6.30	2.15	1.82	3.13	2.70	3.63	1.62
Mg^{2+}	1.62	0.50	0.35	0.51	0.80	0.99	0.34
Na^+	0.04	0.25	0.29	0.27	0.18	0.25	0.14
K^+	0.28	0.23	0.22	0.16	0.14	0.11	0.08
Pb	0.19	0.21	0.18	0.15	0.15	0.14	0.16
SO_4^{2-}	22.29	11.82	2.44	1.07	2.93	4.28	2.75
Cl	0.64	0.45	0.40	0.33	0.37	0.25	0.31
NO_3^-	7.39	3.39	0.44	0.60	1.60	1.60	0.39

Port Colborne	Aug 30	Aug 31	Sep 1	Sep 5	Sep 6	Sep 7	Sep 8	Sep 9	Sep 10	Sep 11	Sep 12	Sep 13	Sep 14
NH_4^+	0.35	1.72	1.58	2.23	3.35	3.33	5.88	3.66	1.72	0.50	1.53	0.60	0.68
Ca^{2+}	1.57	0.93	0.31	0.99	0.85	0.91	1.01	0.50	0.67	1.76	1.33	1.92	0.36
Mg^{2+}	0.59	0.30	0.11	0.36	0.30	0.28	0.32	0.15	0.28	0.72	0.42	0.75	0.14
Na^+	0.10	0.19	0.05	0.72	0.61	0.38	1.21	0.16	0.03	0.03	0.11	0.12	0.08
K^+	0.09	0.08	0.11	0.12	0.11	0.08	0.11	0.08	0.05	0.11	0.09	0.11	0.05
Pb	0.15	0.15	0.18	0.15	0.15	0.16	0.16	0.16	0.15	0.16	0.15	0.15	0.15
SO_4^{2-}	1.28	6.53	4.57	12.20	15.10	19.46	22.87	15.11	5.15	1.57	4.57	2.26	1.57
Cl	0.30	0.34	0.11	0.66	0.49	0.85	0.44	0.25	0.31	0.35	0.33	0.33	0.20
NO_3^-	0.45	1.55	0.35	2.33	1.07	2.36	2.16	0.31	0.58	1.54	1.84	1.26	0.66
Ni	0.07	0.08	0.09	0.36	1.86	0.98	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Co	0.07	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08

Guelph	Oct 24	Oct 25	Oct 26	Oct 27	Oct 28	Oct 29	Oct 30
NH_4^+	0.67	2.13	4.68	4.09	5.66	3.73	4.70
Ca^{2+}	1.97	8.57	6.97	12.40	6.93	7.85	8.73
Mg^{2+}	0.92	3.68	2.16	5.38	3.25	3.76	4.10
Na^+	0.15	0.52	0.34	0.23	0.48	0.48	0.83
K^+	0.17	0.35	0.29	0.34	0.42	0.33	0.47
Pb	0.17	0.17	0.25	0.19	0.16	0.15	0.17
SO_4^{2-}	3.43	12.42	14.38	17.94	22.45	20.17	16.73
Cl	0.41	0.87	1.77	0.95	0.81	0.75	2.07
NO_3^-	4.18	11.00	8.29	13.70	8.47	7.34	7.17

Table A3 (cont'd)

Smiths Falls	Nov 6	Nov 7	Nov 8	Nov 9	Nov 10	Nov 11	Nov 12	Nov 13	Nov 14	Nov 15	Nov 16
NH_4^+	0.31	0.66	1.58	1.26	0.55	4.90	0.37	1.43	1.00	1.94	0.20
Ca^{2+}	0.23	0.19	0.23	0.48	0.36	0.35	0.31	0.33	0.16	0.25	0.43
Mg^{2+}	0.05	0.06	0.04	0.09	0.07	0.07	0.09	0.11	0.06	0.10	0.20
Na^+	0.07	0.11	0.03	0.06	0.17	0.06	0.21	0.23	0.19	0.16	0.06
K^+	0.03	0.03	0.03	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Pb	0.15	0.16	0.17	0.30	0.34	0.29	0.31	0.29	0.32	0.31	0.31
SO_4^{2-}	0.97	1.79	3.56	2.85	0.68	0.58	0.61	2.29	2.12	5.30	0.62
Cl^-	0.09	0.26	0.35	0.30	0.21	0.17	0.18	0.34	0.19	0.19	0.19
NO_3^-	0.29	0.71	1.90	1.94	1.03	0.81	0.61	2.81	1.41	1.06	0.62

* Sample volume is expressed in Table A4

Table A4. Ambient SO_2 Concentrations

Etobicoke (XX)	Aug 14	Aug 15	Aug 16	Aug 17	Aug 18	Aug 22	Aug 23
SO_4^{2-} on filter (ug)	1240.00	251.00	297.00	183.00	333.00	395.00	
volume of air (m3)	26.52	24.20	27.41	33.56	32.57	35.53	32.04
SO_2 (ppb vol)	11.69	2.59	2.71	1.36	2.56	2.78	

Port Colborne	Aug 30	Aug 31	Sep 1	Sep 5	Sep 6	Sep 7	Sep 8	Sep 9	Sep 10	Sep 11	Sep 12	Sep 13	Sep 14
SO_4^{2-} on filter (ug)	52.00	1300.00	373.00	2510.00	4880.00	2110.00	710.00	446.00	246.00	69.00	384.00	483.00	185.00
volume of air (m3)	33.66	32.18	28.43	33.43	32.85	31.76	31.53	31.89	32.69	31.18	33.07	33.27	30.48
SO_2 (ppb vol)	0.39	10.10	3.28	18.77	37.14	16.61	5.63	3.50	1.89	0.55	2.90	3.63	1.52

Guelph	Oct 24	Oct 25	Oct 26	Oct 27	Oct 28	Oct 29	Oct 30
SO_4^{2-} on filter (ug)	54.00	295.00	186.00	245.00	1060.00	731.00	
volume of air (m3)	29.42	28.82	20.38	26.20	31.04	33.26	30.00
SO_2 (ppb vol)	0.46	2.56	2.28	2.34	8.54	5.49	

Smith Falls	Nov 6	Nov 7	Nov 8	Nov 9	Nov 10	Nov 11	Nov 12	Nov 13	Nov 14	Nov 15	Nov 16
SO_4^{2-} on filter (ug)	5.00	39.00	142.00	59.00	75.00	112.00	72.00	62.00	63.00	50.00	29.00
volume of air (m3)	34.02	30.79	28.96	16.51	14.62	17.36	16.35	17.43	15.57	16.05	16.22
SO_2 (ppb vol)	0.04	0.32	1.23	0.89	1.28	1.61	1.10	0.89	1.01	0.78	0.45

Table A5. PRECIPITATION CHEMISTRY

Etobicoke (XX)	AVG	STD	MAX	MIN	Aug11-14	Aug 14-15	Aug 15	Aug15-16	Aug 16-21
NH_4^+ (mg/L)	1.28	0.44	1.89	0.86	1.03	1.89	0.89	0.86	1.71
Na^+ (mg/L)	0.05	0.04	0.13	0.02	0.02	0.13	0.02	0.04	0.06
Ca^{2+} (mg/L)	1.29	1.05	3.30	0.45	0.68	3.30	0.66	0.45	1.35
Mg^{2+} (mg/L)	0.39	0.37	1.11	0.09	0.18	1.11	0.19	0.09	0.38
K^+ (mg/L)	0.04	0.01	0.06	0.02	0.02	0.06	0.02	0.04	0.04
Ni (ug/L)					<10.00	<10.00	<10.00	<10.00	<10.00
Pb (ug/L)	6.60	5.92	18.00	2.00	2.00	2.00	6.00	5.00	18.00
Co (ug/L)					<10.00	<10.00	<10.00	<10.00	<10.00
NO_3^- (mg/L)	6.25	3.40	12.68	2.92	5.05	12.68	6.25	2.92	6.34
SO_4^{2-} (mg/L)	9.35	4.18	15.69	5.15	6.04	15.69	6.94	5.15	12.93
Cl^- (mg/L)	0.57	0.48	1.47	0.08	0.56	1.47	0.41	0.31	0.08
F^- (mg/L)					<0.50	<0.50	<0.50	<0.50	<0.50
H^+ (umoles/L)	108.98	22.09	125.89	79.43	104.71	-	125.89	79.43	125.89
Conductivity (uS/cm)	69.68	38.01	119.30	15.70	15.70	119.30	65.20	44.20	104.00

Port Colborne	AVG	STD	MAX	MIN	Aug28-30	Aug30-Sep1	Sep 7	Sep 7	Sep 7	Sep 7-9	Sep 11-14	Sep 14-15
NH_4^+ (mg/L)	0.63	0.43	1.54	0.20	0.51	0.20	0.35	0.57	0.62	1.03	1.54	0.21
Na^+ (mg/L)	0.05	0.03	0.09	0.02	0.08	0.02	0.09	0.03	0.02	0.09	0.09	0.02
Ca^{2+} (mg/L)	0.59	0.73	2.45	0.07	0.58	0.16	0.36	0.18	0.30	0.65	2.45	0.07
Mg^{2+} (mg/L)	0.16	0.22	0.73	0.02	0.13	0.03	0.14	0.06	0.05	0.09	0.73	0.02
K^+ (mg/L)	0.02	0.01	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.02
Ni (ug/L)					140.00	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00
Pb (ug/L)	11.14	7.14	26.00	2.00	26.00	12.00	14.00	9.00	5.00	-	10.00	2.00
Co (ug/L)					<10.00	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00
NO_3^- (mg/L)	3.88	2.70	9.98	1.66	4.61	2.09	1.82	3.25	1.66	5.79	9.98	1.80
SO_4^{2-} (mg/L)	8.34	8.53	30.25	2.57	8.16	3.39	4.54	5.47	2.57	8.58	30.25	3.73
Cl^- (mg/L)	0.66	0.45	1.76	0.33	0.87	0.44	0.49	0.36	0.37	0.64	1.76	0.33
F^- (mg/L)					<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
H^+ (umoles/L)	66.42	37.19	120.23	5.01	100.00	48.98	53.70	72.44	5.01	120.23	-	64.57
Conductivity (uS/cm)	86.73	92.01	324.00	17.70	78.60	55.50	38.20	54.90	17.70	85.60	324.00	39.30

Table A5 (cont'd)

Guelph	AVG	STD	MAX	MIN	Oct 16-17	Oct 17-18	Oct 19-20	Oct 21
NH_4^+ (mg/L)	0.61	0.41	1.11	0.19	0.93	0.19	0.21	1.11
Na^+ (mg/L)	0.03	0.02	0.07	0.02	0.02	0.02	0.02	0.07
Ca^{2+} (mg/L)	0.59	0.22	0.84	0.26	0.70	0.26	0.84	0.55
Mg^{2+} (mg/L)	0.23	0.14	0.46	0.10	0.22	0.10	0.46	0.15
K^+ (mg/L)	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.02
Ni (ug/L)					<10.00	<10.00	<10.00	<10.00
Pb (ug/L)					<2.00	<2.00	<2.00	<2.00
Co (ug/L)					<10.00	<10.00	<10.00	<10.00
NO_3^- (mg/L)	3.39	2.30	7.08	0.81	3.20	0.81	2.45	7.08
SO_4^{2-} (mg/L)	3.30	1.13	4.98	1.85	4.98	1.85	2.90	3.48
Cl^- (mg/L)	0.34	0.04	0.39	0.27	0.39	0.35	0.35	0.27
F^- (mg/L)					<0.50	<0.50	<0.50	<0.50
H^+ (nmoles/L)	45.76	32.96	95.50	11.22	54.95	21.38	11.22	95.50
Conductivity (uS/cm)	30.33	15.60	52.00	13.90	38.20	13.90	17.20	52.00

Smith Falls	AVG	STD	MAX	MIN	Nov 5	Nov 6-7	Nov 8	Nov 11-12	Nov 13-14	Nov 14-15	Nov 15-16	Nov 16-17	Nov 17-18
NH_4^+ (mg/L)	0.47	0.45	1.42	0.04	0.31	0.08	0.43	1.42	1.03	0.61	0.10	0.04	1.14
Na^+ (mg/L)	0.14	0.06	0.29	0.07	0.16	0.11	0.12	0.15	0.29	0.12	0.07	0.08	0.20
Ca^{2+} (mg/L)	0.69	0.98	3.30	0.05	0.41	0.13	0.16	0.85	1.90	0.25	0.05	0.10	0.07
Mg^{2+} (mg/L)	0.18	0.33	1.10	0.02	0.05	0.03	0.05	0.16	0.14	0.03	0.02	0.03	0.03
K^+ (mg/L)	0.04	0.02	0.08	0.02	0.03	0.04	0.02	0.06	0.08	0.02	0.02	0.02	0.02
Ni (ug/L)					-	-	-	-	-	-	-	-	-
Pb (ug/L)					-	-	-	-	-	-	-	-	-
Co (ug/L)					-	-	-	-	-	-	-	-	-
NO_3^- (mg/L)	3.09	1.80	5.41	0.51	2.46	0.99	4.27	4.93	5.41	3.62	0.94	0.51	4.70
SO_4^{2-} (mg/L)	2.45	1.41	5.28	0.51	2.86	0.51	2.91	3.47	5.28	2.77	2.32	0.67	1.30
Cl^- (mg/L)	0.41	0.19	0.83	0.22	0.35	0.22	0.22	0.57	0.54	0.30	0.31	0.33	0.83
F^- (mg/L)					<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
H^+ (umoles/L)	37.16	32.68	87.10	0.59	63.10	11.48	87.10	23.99	83.18	52.48	8.71	3.89	0.59
Conductivity (uS/cm)	27.16	17.72	57.80	5.09	35.60	8.46	46.30	31.40	57.80	36.50	8.01	5.09	15.30

Table A6. Meteorological Data

Site	Date (1989)	Wind Speed (m/s)	Wind Direction (degree)	Temperature (C)	Relative Humidity (%)
Etobicoke	Aug 8	1.40	178.99	17.26	52.45
	Aug 9	2.34	197.10	17.91	55.76
	Aug 10	1.63	165.50	20.93	65.90
	Aug 11	0.94	167.53	21.27	67.06
	Aug 12	1.54	157.62	22.08	64.87
	Aug 13	1.36	159.40	20.70	78.60
	Aug 14	1.41	198.79	21.00	73.03
	Aug 15	1.23	208.30	19.18	88.01
	Aug 16	2.20	258.75	19.96	66.37
	Aug 17	2.37	145.89	17.69	61.65
	Aug 18	2.80	156.77	17.67	62.98
	Aug 19	2.01	164.12	19.34	75.33
	Aug 20	2.87	180.77	20.68	87.46
	Aug 21	2.65	272.03	22.54	70.45
	Aug 22	1.58	208.67	18.63	80.27
	Aug 23	3.02	260.14	20.28	73.28
	Aug 24	2.42	157.81	17.35	67.42
	Average	1.99	190.48	19.67	70.35
	Std. Dev.	0.63	38.53	1.65	9.74
Port Colborne	Aug 31	3.06	201.51	21.93	72.91
	Sep 1	4.06	242.13	20.78	86.37
	Sep 2	2.58	243.00	17.92	64.08
	Sep 3	1.49	154.22	15.64	68.23
	Sep 4	2.64	139.85	17.97	60.07
	Sep 5	3.65	207.33	20.24	67.57
	Sep 6	2.70	215.13	20.90	77.64
	Sep 7	1.83	192.03	21.73	77.83
	Sep 8	3.44	223.03	22.31	88.72
	Sep 9	3.06	223.97	23.19	86.49
	Sep 10	2.84	206.59	20.71	82.62
	Sep 11	1.60	118.37	18.29	76.85
	Sep 12	1.73	176.81	17.54	79.05
	Sep 13	2.46	53.33	16.06	74.32
	Sep 14	3.28	56.99	12.72	88.46
	Sep 15	2.12	28.91	11.84	92.41
	Average	2.66	167.70	18.74	77.73
	Std. Dev.	0.74	67.35	3.26	9.21

Table A6 (cont'd)

Site	Date (1989)	Wind Speed (m/s)	Wind Direction (degree)	Temperature (C)	Relative Humidity (%)
Guelph	Oct 23	1.55	199.90	11.39	64.39
	Oct 24	0.78	177.65	12.38	80.34
	Oct 25	0.71	146.71	12.30	89.89
	Oct 26	0.76	179.36	11.84	84.41
	Oct 27	0.59	157.44	10.73	83.95
	Oct 28	0.87	138.78	10.12	81.84
	Oct 29	0.95	123.05	10.20	72.82
	Oct 30	1.46	122.73	9.92	72.47
	Average	0.96	158.20	11.11	78.76
	Std. Dev.	0.33	26.24	0.94	7.71
Smiths Falls	Nov 3	3.45	317.89	0.03	70.35
	Nov 4	1.68	212.85	-4.36	57.83
	Nov 5	3.33	144.95	4.35	59.16
	Nov 6	4.98	237.73	8.98	76.85
	Nov 7	2.05	160.16	2.97	85.08
	Nov 8	3.05	65.44	2.39	97.02
	Nov 9	3.06	193.64	7.09	89.50
	Nov 10	2.91	230.87	3.40	78.67
	Nov 11	5.24	238.57	4.00	77.37
	Nov 12	3.24	299.67	-0.21	54.59
	Nov 13	2.29	137.27	-0.28	74.02
	Nov 14	1.69	115.80	4.24	93.92
	Nov 15	2.09	108.70	6.83	96.17
	Nov 16	6.00	210.60	8.42	78.31
	Nov 17	5.52	253.56	-1.77	63.08
	Average	3.37	195.18	3.07	76.79
	Std. Dev.	1.37	69.58	3.73	13.45